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ScienceDirect

Procedia Engineering 1 (2009) 47–50

Procedia Engineering

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Mesomechanics 2009

Computational adaptive structure assessment of c-130 flaperon

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Received 11 March 2009; revised 6 May 2009; accepted 12 May 2009

Abstract

Computational software for composites has been enhanced to simulate the shape changes for piezo-electrically controlled structures. The Structural Health Monitoring (SHM) and Morphing Evaluation considered Durability and Damage Tolerance (D&DT) and reliability analysis utilizing the GENOA Multi-scale Progressive Fracture Analyzer (PFA). SHM software is now developed to simulate and validate probabilistic design methodology to identify piezoelectric composite shape control as well as damage progression due to piezoelectric control of composite airfoils in airframe and engine applications. Given the requirements of airfoil shape control and limits, the GENOA composite mechanics module is used to determine basic parameters and choices of sandwich structure and piezo-composite architecture that will be compatible with the shape control needs. The identified candidate design parameters are evaluated via GENOA PFA for functional performance with respect to shape control as well as structural durability under service loading. The piezo-adaptive shape simulations are verified by comparison with selected closed form solutions and test data from the literature. The piezoelectrically controlled composite airfoil structure is optimized based on minimum weight, minimum damage, and maximum performance requirements.

Keywords: composites; control; durability; morphing; optimal design; piezoelectric; probabilistic design

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1. Introduction

This paper summarizes the development of morphing structure simulation capability. Alpha STAR Corporation (ASC) has developed commercially viable software in the field of piezoelectric control and durability of composite structures. The new capability is integrated into the GENOA suite of composite [1] structures virtual testing software products. Computational software for composites has been enhanced to simulate the shape changes for piezo-electrically controlled morphing structures [2]. The GENOA Progressive Fracture Analyzer (PFA) is now developed to simulate and validate probabilistic design methodology to identify piezoelectric composite shape control as well as damage progression due to piezoelectric control of composite airfoils in aircraft and engine

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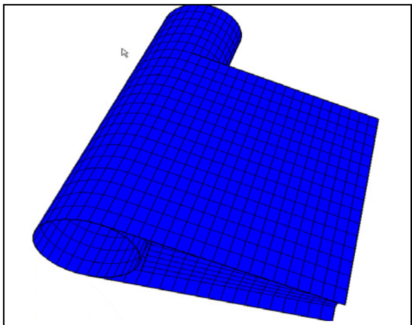
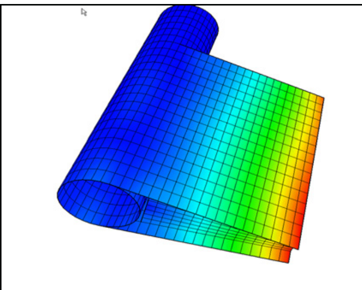
doi:10.1016/j.proeng.2009.06.013

applications. Given the requirements of airfoil shape control and limits, the GENOA composite mechanics module is used to determine basic parameters and choices of sandwich structures and piezo-composite architectures that will be compatible with the shape control needs. The identified candidate design parameters are evaluated via GENOA PFA for functional performance with respect to shape control as well as structural durability under probabilistic fatigue loading. The piezo-adaptive shape simulations are verified by comparison with selected closed form solutions and test data from the literature [3]. The piezoelectrically controlled composite airfoil structure is optimized based on minimum weight, minimum damage, and maximum performance requirements. The scale model of a stiffened composite airfoil panel and actuator system is utilized for proof of the baseline concept. Based on the results of the GENOA virtual testing software recommendations are provided for the probabilistic design of a piezoelectrically controlled composite airfoil. The final paper will include the test cases for the developed validated methodology for effective design of piezoelectrically controlled airfoils. Structural optimization will be carried out (a) prior to probabilistic design evaluation and (b) after probabilistic evaluation. The Polymeric Composite Module in GENOA program was enhanced to compute piezoelectric strains from electrical input variables. These strains then become input values to the enhanced MHOST [4] finite element solver.

2. Analysis of Damage Progression in Piezoelectrically Controlled Flap

A flap model was constructed using Mindlin type shell elements. The model contains 1654 nodes and 1600 elements as shown in Figure 1a. The piezoceramic fibers are included in the surface layer. Figure 1b shows the flap deflection pattern induced by application of voltage to piezoelectric fibers. Figure 1c shows locations of damage initiation due to piezoelectric strains. At the locations indicated damage initiation mode is by ply transverse tensile failures.


a) FE Model


b) Z Displacement with Voltage input =10V

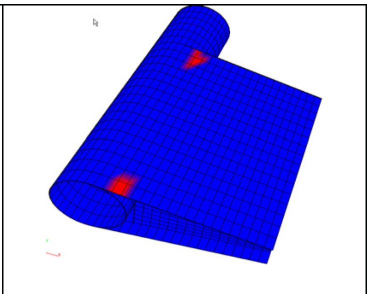
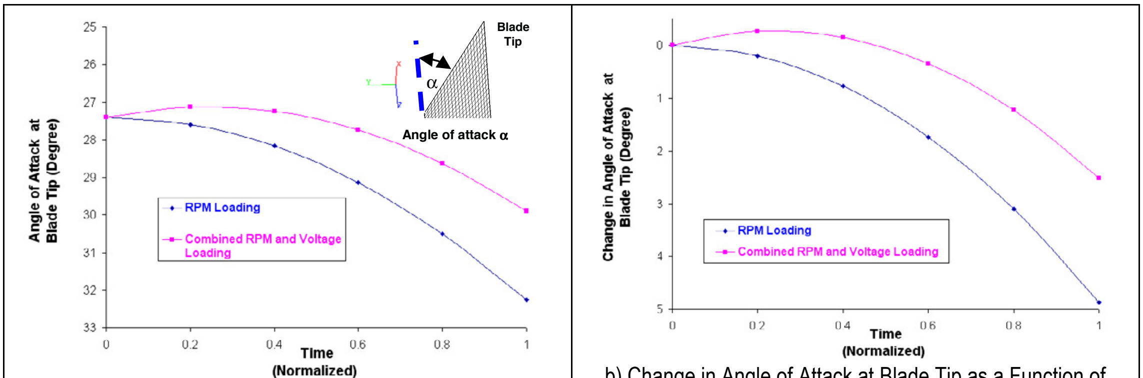

c) Damage Initiation location (red), as result of increase in Voltage

Figure 1. (a) finite element model; (b) piezoelectrically induced displacements; (c) damage initiation locations

3. Piezoelectrically Controlled Composite Airfoil

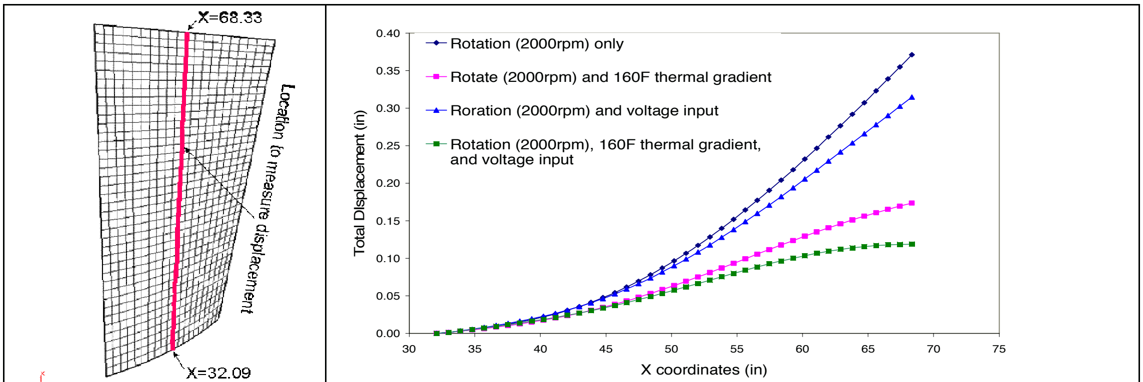
A fan blade of a large subsonic engine (e.g. GE 90+) is modeled using Mindlin type shell elements (number of Nodes = 861, number of Elements = 800). The material properties used in the simulation are listed in Tables 2 and 3. A. quasi isotropic ply lay layup was considered as blade configuration. A piezoelectric ceramic layer was added to the bottom of the laminate. Figure 1 shows the finite element model. Figure 2 depicts a plot of the angle of attack as a function of applied loading (centrifugal rpm loading and combined rpm and voltage input). Figures 3 shows, Pressure Displacement Curve with/without Piezoelectric Voltage Input Application. It is clear that the application of voltage input minimizes the deformations resulting from the rotational load.



a) Angle of Attack at Blade Tip as a Function of Applied Loading

b) Change in Angle of Attack at Blade Tip as a Function of Applied Loading

Figure 2. Angle of attack modification with piezoelectric voltage input



Total Displacement

Figure 3. Pressure Displacement Curve with/without Piezoelectric Voltage Input Application

4. Probabilistic Optimization of Composite Airfoil Control

Probabilistic analysis was performed to assess the scatter in the blade mid span tip displacement subject to uncertainties in the piezoelectric constants, graphite fiber and epoxy matrix stiffness, composite fabrication (fiber volume ratio and void volume ratio), blade length, blade thickness, voltage applied and rotational speed. As indicated in Figure 4, the blade displacement had a scatter of 0.19 in based on the random variables statistics identified in the same figure. Most of the blades would exhibits tip displacement close to that of the mean value (0.118”) while very few blades would have a displacement close to 0.024” or 0.214”. High reliability design (0.999) requires that the blade displacement be kept equal or less to that of the 0.001 probability (that is 0.024”). One derived benefit from probabilistic analysis is the ability to quantify the relative effect of scatter in the random variables on the structural response. The effect of scatter in the random variables (piezoelectric constants, stiffness, fabrication parameters, geometry and load) was evaluated on the blade mid span tip displacement. Probabilistic sensitivity analysis shows that the influential random variables are in order of importance: rotational speed, epoxy matrix modulus, fiber volume ratio, thickness, piezoelectric constants, length, void volume ratio, fiber longitudinal modulus, thermal gradient, and voltage.

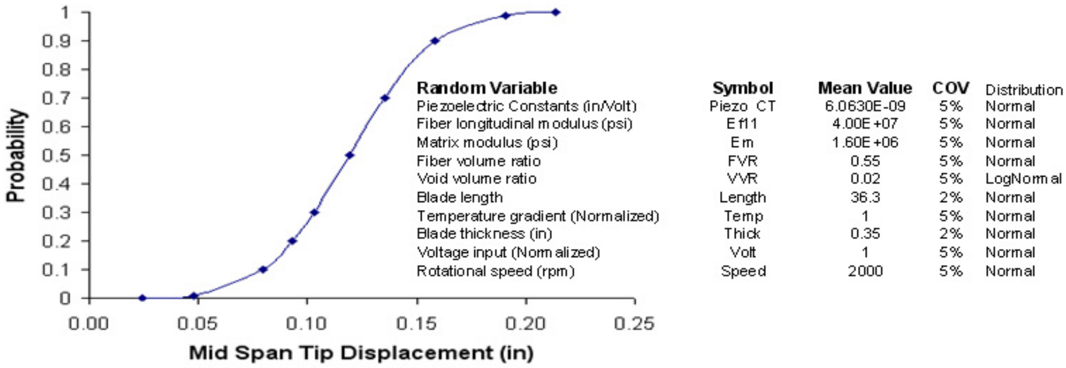


Figure 4. Probabilistic blade mid-blade tip displacement (combined rpm, thermal gradient, and piezoelectric voltage)

Table 1 shows the most probable design obtained from the probabilistic simulation. The low probability design is denoted as low bound design while the high probability design is denoted as the high bound design. These bounds can be used as optimized limits for blade reliability based design. One can decouple the list of random variables to have the material and fabrication variables as random variables while considering the geometry variables as design variables for deterministic optimization. The process entails performing deterministic optimization followed by uncertainty analysis to assess reliability under given design loading condition.

Table 1. Blade mean and optimized bounded designs

Random Variable	**Symbol**	***Mean Design***	***Low Bound Design***	***High Bound Design***
Piezoelectric Constants (in/Volt)	Piezo_CT	6.0630E-09	6.3662E-09	5.7720E-09
Fiber longitudinal modulus (psi)	Ef11	4.00E+07	3.88E+07	4.12E+07
Matrix modulus (psi)	Em	1.60E+06	1.70E+06	1.49E+06
Fiber volume ratio	FVR	0.55	0.584	0.515
Void volume ratio	VVR	0.02	0.021	0.019
Blade length	Length	36.3	35.619	36.984
Temperature gradient (Normalized)	Temp	1	0.988	1.012
Blade thickness (in)	Thick	0.35	0.357	0.343
Voltage applied (Volt)	Volt	200000	197377	202638
Rotational speed (rpm)	Speed	2000	1850	2151
Response: Mid Span Tip Displacement (in)		***0.024***	***0.118***	***0.214***

5. Conclusions

Piezoelectric loads influence the magnitude of stresses as well as the shape of composite structures. Shape modification requires significant voltage input. Piezoelectric stresses affect structural durability. Probabilistic optimization of design parameters could performance and durability of piezoelectric composite airfoils.

References

1. http://www.ascgenoa.com/main/
2. D. A. Saravanos, "Mixed Laminate Theory and Finite Element for Smart Piezoelectric Composite Shell Structures", AIAA Journal Vol. 35, No. 8, August 1997.
3. Minnetyan L, Chamis C C, Abdi F."Damage Tolerance of Fiber Composite Airfoils with Piezoelectric Adaptive Control System," Proc. of the AIAA/ASME/ASCE/AHS/ASC SDM Conference, Atlanta, Ga, 3-6 April 2000, Paper No. AIAA 2000-1504, pp. A00-24559 (7p.).
4. S. Nakazawa, "The Mhost Finite Element Program, 3-D Inelastic Method for Hot Structure Components", Volume 1 Theoretical and User Manual, NASA Technical Contract Report CR-182205, March, 1991.